Life Cycle Management for Mining Machinery.

By W.F. Barkhuizen,
Prof. L. Pretorius

SUMMARY

Until very recently reactive maintenance was still used in the mining industry. Equipment failures occurred without warning and resulted in catastrophic breakdowns and large production losses and maintenance cost.

As a result, the mining industry turned to preventative maintenance that focused on changing parts before they fail. Although preventative maintenance was an improvement over reactive maintenance practices, equipment reliability did not necessarily improve. Next came predictive diagnostics, which monitored the health of components within assemblies, and thereby predicting the life expectancy of assemblies through vibration analysis, infrared thermography, lubrication and oil analysis and ultrasonic detection.

However, the level of success could not be achieved. Many hours and a lot of money are spent in developing and implementing a maintenance management system, but without the correct approach, efficient maintenance might not be achieved. The overall objective of the dissertation is to introduce a logical approach to managing the maintenance of mining equipment over the economical life of the equipment. This concept can be defined as Life Cycle Management.

The research included in the dissertation is partially aimed at developing the Life Cycle Management program for P&H MinePro Services A division of Joy Global (South Africa) (Pty) Ltd.

The dissertation focuses on the cradle to grave approach of maintenance for mining machinery, referred to as the Life Cycle Management of Mining Machinery.[1]

INTRODUCTION.

Before the introduction of a proactive approach to maintenance in the mining industry, equipment failures occurred without warning, leaving the customer in a catastrophic situation as a result of the major production losses.

The introduction of preventative maintenance, and the progression from a reactive approach to maintenance to a proactive mindset resulted in a cost-effective method of maintaining mining equipment.

Although maintenance costs were reduced the level of success could not be achieved. This lead to the introduction of Life Cycle Management which in essence combines the various maintenance tactics and functions of maintenance management to develop a maintenance plan and strategy to ensure equipment reliability and availability are increased.
BACKGROUND.

Developments in the industry as systems and machines became increasingly complex resulted in a transformation in the way failures is understood.[3]

During the first quarter of the 20th century maintenance approaches were very different from the current maintenance practice. Equipment was generally very robust and easy to maintain. The mindset of the industry was also amenable to equipment failure and production losses due to equipment unavailability.[3]

Shortly here after, this reactive approach to maintenance started to change as the industry became more complex. This lead to the maintenance approach known today as the preventative maintenance approach. The industry worked towards preventing failures before they actually happen, these resulted in less manual intervention and reduced manpower requirements.[3]

The evolution from the corrective maintenance approach to the preventative maintenance approach, was believed to have been caused by the fact that it was realised as equipment gets older it becomes more susceptible to failures and is more likely to fail. This knowledge was applied to the sub-assemblies or smaller components within a piece of equipment, with the intention to maintain the items that cause the equipment to fail.[2]

This chain of thought led to the development of a model for maintenance. This model was based on the fact that planned intervention before the failure occurs, can reduce the likelihood of failure. If the failures still occur the model suggests that the intervention was not early enough in the life cycle of the equipment.[3]

However, in some cases it was found that the reliability of the equipment was not related to the overall frequency of the maintenance, as suggested by the model, and also the belief that reliability declined with increasing age, could not be proven. It became obvious that too much emphasis was placed on conducting the maintenance at the correct intervals.[3]

This led to the development of Reliability Centred Maintenance (RCM).

The development of reliability centred maintenance was initiated by a task force consisting of members from the Federal Aviation Administration (FAA) and the airlines in the United States of America. The programs developed by the task team is now known as Maintenance Steering Group 1 (MSG-1). MSG-1 was eventually reviewed and became MSG-2 and later MSG-3. MSG-3 was applied to other industries and became known as Reliability Centred Maintenance (RCM).[3]

DEVELOPING A MAINTENANCE STRATEGY.

The life cycle concept introduces a start and finish approach to every process. The life cycle in this context is the economical life of mining equipment which starts on the day the machine is put into production and ends on the day the machine is taken out of production and sold at salvage value.
Mining equipment is often procured on the basis of life cycle cost, instead of first cost, illustrating the need for efficient and cost-effective life cycle management.

To start any business, a business strategy must be developed, the same applies for any maintenance strategy. A maintenance strategy is determined by establishing the maintenance management goals.

**Establish Maintenance Management Goals**

An approach to solving a problem might be to take one step back and look at the problem from a different perspective. To be able to identify what type of maintenance strategy will be followed the maintenance management goals must be identified. Once the goals are known, the approach to planning, organising and controlling the maintenance effort can be established.

Answering various questions might be the easiest way of establishing the maintenance management goals.
- What is the function of maintenance management?
- What is the expectation from the customer on the machine?
- How can value be added?
- How can utility be achieved?

Consider the following scenario. A person has a specific goal, in order for the person to achieve his goal he puts together a business strategy. To achieve this strategy successfully, certain resources are identified as essential. After establishing that one of the resources required is a drill, the person sets the standards of performance, specifications, function and purpose for this asset. The asset is procured and put into production, once the machine is in production the machine must be operated and maintained. After the asset’s economic usefulness is ended, it is disposed of.

Once the maintenance management goals are known, the maintenance plan can be constructed.

**The Maintenance Plan.**

Consider a front-end loader loading coal into trucks. The foremost reason for maintenance on this machine is to maintain the machine’s condition, but maintaining the machine’s condition should also be aimed at maintaining the amount of coal loaded into the truck; maintenance procedures should be aim at improving both machine condition and machine production.

From the background discussion it is very likely that there are many approaches to developing a maintenance plan.

**Construction of the maintenance plan.**

One of the approaches to developing a maintenance plan that will form part of the life cycle management of equipment, is to visualise the construction of the maintenance plan and all of the components as similar to the construction of a house.
As illustrated in Figure 4.1., the maintenance requirements form the foundations of the house, without the foundations in place the maintenance plan development cannot continue.[23]

The maintenance requirements are all the work processes needed to develop the maintenance plan for the equipment. These work processes include:

- Generating works orders and job cards.
- Organise and track inventory.
- Track equipment history.
- Scheduling of tasks and project equipment failure.
- Maintain labour records.
- Allocate resources.
- Planning and ordering of spare parts.
- Forecasting.
- Management of service exchange units.

The walls form the building blocks and consist of the resources required to achieve the maintenance requirements. [23] Resources include:

- Parts and inventory.
- Skilled site personnel.
- Tools and equipment.
- Stores and offices.

The roof represents the maintenance control systems. The maintenance control system ensures that all the information collected, is used to improve the maintenance plan.

The next step in the development of the maintenance plan is to establish the priority of the work processes that must be actioned, it is important to ascertain the current strengths and weaknesses in the maintenance plan.
Prioritising the Work Processes.

A Bell-Mason type spider diagram can be constructed from the actual case study data (Compiled from a maintenance audit) as illustrated in Figure 2. It should be clear that knowing the current status of the work processes it is possible to highlight the necessary improvement in work processes for the case study.

Figure 2. Strengths and Weaknesses of the Work Processes. [Case Study]

Figure 2. Indicates that for the case study the systems implemented, should improve the following areas in the priority listed:

- Work order system.
- Administration.
- PM Plan.
- Parts Management
- Reporting.

Establishing the priorities of the maintenance system determines the focus point of the maintenance plan.

The next step is to set a vision or objective, this will be the new maintenance plan, in essence, the new maintenance plan will be the path from the present to the vision.

Developing the Work Processes.

The maintenance plan consists of work processes. Work processes should be developed for the following processes:

- Work order management.
- Equipment records and history.
- Preventative maintenance tasks and scheduling.
• Costing and budgeting.
• Materials management.
• Labour skills capacity planning.

These processes are used to control the use of resources in the maintenance plan. A standard operating procedure can be compiled which is a document used to describe all the work procedures and ensure that the work processes are completed and managed using a certain quality standard set by the customer.[15]

The quality standards are determined by the customer’s needs. A section that will form part of the standard operating procedures will be the reporting. One of the customer’s needs might be a monthly report compiled on the 15th of each month and submitted before the 20th of each month. To be able to compile this report the maintenance data must be gathered and analysed before the 15th and this process is typically one of the sections to be documented in the standard operating procedures.

Optimisation of the maintenance plan starts with the actual data gathered. The next step will be to analyse the data and make use of the information gathered. A typical monthly report should contain the Key Performance Indicators (KPI). A portion of the monthly report developed for the case study is attached in Appendix A.[15]

The key to analysing the data is to compile KPI for a specific piece of equipment. The KPI can be used to determine on which aspects or parts the maintenance should focus, depending on the objective of the maintenance.

The objective of the maintenance approach for example, can be to reduce maintenance cost, or on the other hand to improve availability no matter what the maintenance cost will be. Thus, these two objectives will focus on different aspects of maintenance.[18]

A “champion” or owner must be appointed to manage the work processes, this person is the maintenance planner.

CONTROLLING

The maintenance planner will need continuous feedback from the site personnel in the form of key performance indicators to be able to perform the control and planning function.

Planning Costs

Most products are brought into being and utilised over a life cycle. The maintenance life cycle starts when a machine is at zero running hours and ends with phaseout and disposal or selling the machine at salvage value.

The variable cost varies during the life cycle of the machine. This variance can be linked to the preventative maintenance strategy and coincides with the planned parts change-out.[18]
The life cycle costs of the equipment follows a trend similar to that of the bathtub curve. The following can be seen from figure 3:

- A major rebuild is scheduled for the period 18000 hrs to 24000 hrs. to improve reliability some components are rebuild at 18000 hrs while other components are scheduled for 24000 hrs.
- The life cycle of the maintenance agreement is 48000 hrs although major components are replaced during a midlife service.
- The second portion of the maintenance agreement from 24000 hrs to 48000 hrs is different to the period from 0 hrs to 24000 hrs. The difference in cost is a result of the difference in maintenance strategy. In the last period maintenance costs are kept low to lower the salvage value of the machine at the end of the agreement. During this period the guaranteed availability will also be lower.

![Figure 3. Variable Maintenance Costs.](image)

**Reliability and Risk.**

Why is reliability important in maintenance management? The mean number of failures in a certain time period determines the reliability of a machine. Maintenance is partially performed to reduce failures, which improves reliability. To be able to reduce the possibility, or risk of having a failure, a risk analysis can be implemented. Possible failures can be approached in a more planned and proactive manner by introducing a risk analysis to manage reliability.
Developing a Risk Analysis.

Reliability generally affects availability, and maintainability is also relevant. Reliability and maintainability can be related to availability by : [7]

\[
\text{Availability} = \frac{\text{MTBF}}{\text{(MTBF + MTTR)}} \tag{1}
\]

Risks can be identified and managed by setting up a Risk Analysis for the particular risk area on the machine. The development of the risk analysis presented in the dissertation is based on the flow diagram presented in figure 4, derived from a case study.

![Figure 4. Logical flow of reliability plan. [Case Study]](image)

The Risk Matrix.

The first step to managing risks is to quantify the risks. Risks can be quantified by allocating a certain value to each type of risk and classifying the risks. When risks are managed it is important to quantify the impact of the risk and the likelihood of the risk. The impact is a measurement of the damage the risk can cause, while the likelihood is a measure of how likely it is for the risk to occur.

The following explanation should clarify the use of a risk matrix:

When the impact and likelihood of a risk is quantified it is important to customise the steps of likelihood and impact according to the specific application. For the purpose of the case study it is assumed that the different levels of impact can be defined as set-out in Table 1. It is also assumed that the likelihood can be defined as set-out in Table 2.

The likelihood and impact tables are combined to form the risk matrix for this application, represented by Table 3.
<table>
<thead>
<tr>
<th>LEVEL</th>
<th>DESCRIPTOR</th>
<th>DETAILED DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Insignificant</td>
<td>No Downtime, No Cost, No Delaytime.</td>
</tr>
<tr>
<td>2</td>
<td>Minor</td>
<td>Can be resolved within 24 Hrs. Low Financial Impact.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>More than 24 Hrs downtime. Medium Financial Impact.</td>
</tr>
<tr>
<td>4</td>
<td>Major</td>
<td>Less than 72 Hrs downtime. High Financial Impact.</td>
</tr>
<tr>
<td>5</td>
<td>Catastrophic</td>
<td>More than 72 Hrs downtime. Hugh Financial Impact.</td>
</tr>
</tbody>
</table>

Table 1. Illustrative Measures of Impact.[Case Study]

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>DESCRIPTOR</th>
<th>DETAILED DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Almost Certain</td>
<td>Is expected to occur in most circumstances</td>
</tr>
<tr>
<td>B</td>
<td>Likely</td>
<td>Will probably occur in most circumstances.</td>
</tr>
<tr>
<td>C</td>
<td>Possible</td>
<td>Might occur at some time.</td>
</tr>
<tr>
<td>D</td>
<td>Unlikely</td>
<td>Could occur at some time.</td>
</tr>
<tr>
<td>E</td>
<td>Rare</td>
<td>May occur only in exceptional circumstances</td>
</tr>
</tbody>
</table>

Table 2. Illustrative Measures of Likelihood.[Case Study]

<table>
<thead>
<tr>
<th>LIKELIHOOD</th>
<th>IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>H</td>
</tr>
<tr>
<td>B</td>
<td>M</td>
</tr>
<tr>
<td>C</td>
<td>L</td>
</tr>
<tr>
<td>D</td>
<td>L</td>
</tr>
<tr>
<td>E</td>
<td>L</td>
</tr>
</tbody>
</table>

Table 3. Risk Matrix. [Case Study]

The risk matrix makes use of the impact and likelihood of each risk to identify risk as an Extreme Risk, High Risk, Medium Risk or Low Risk, represented in Table 4.

<table>
<thead>
<tr>
<th>LEGEND</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Extreme Risk</td>
</tr>
<tr>
<td>H</td>
<td>High Risk</td>
</tr>
<tr>
<td>M</td>
<td>Medium Risk</td>
</tr>
<tr>
<td>L</td>
<td>Low Risk</td>
</tr>
</tbody>
</table>

Table 4. Legend for Risk Matrix (Table 3.)

A customised risk model is developed for each specific machine, the reason being that each machine has a different application, value and utility, working in specified conditions and requiring a certain performance. The model is constructed of a risk
register, a risk treatment, risk action plans and a risk implementation plan, which will be discussed individually.

**The Risk Register.**

When comparing the risk analysis to the maintenance plan, the risk register forms the foundation of the risk analysis. The risk register contains the majority of information on the risks and serves as a summary of the technical information from the engineering personnel and the financial information from the accounting personnel.

The risk register contains the following:

- A reference number for each risk. This number is used to combine the risk register with the risk treatment, risk action plan and risk implementation plan.
- A description of the risk detailing what can happen when the risk occurs and how it can happen.
- Consequences of a risk happening: Using the qualitative measure of likelihood and impact (refer to Table 1. and Table 2.) it is determined what the impact and likelihood of each risk is.
- Level of the risk before the action plan is implemented: The level of the risk before the action plan is implemented, is determined from the risk matrix (refer to Table 3. and Table 4.).
- Machine downtime before the action plan is implemented: The estimated downtime for the machine caused by the event, includes the repair or installation of parts and testing of the machine after machine has been repaired.
- Downtime cost before the action plan is implemented: The downtime cost is determined by the following equation:
  \[
  \text{Downtime Cost} = \text{Downtime in hours} \times \text{Variable cost} \quad [2]
  \]
- Repair cost before the action plan is implemented: The repair cost is determined by the following equation:
  \[
  \text{Repair Cost} = \text{Cost of parts} + \text{Cost of labour (Including subcontractor labour)} \quad [3]
  \]
- Level of risk after the implementation of the action plan: The level of the risk after the implementation of the action plan is again determined from the risk matrix (refer to Table 3. and Table 4.). Taking into consideration the influence of the action plan on the impact and consequence.
- Machine downtime after the implementation of the action plan: The estimated machine downtime is determined with the action plan in place.
- Downtime cost after the implementation of the action plan: The cost of the downtime is determine by equation 2. Taking into consideration the influence of the action plan on the downtime hours.
- Repair cost after the implementation of the action plan: The repair cost is determined by equation 3. Taking into consideration the influence of the action plan on the labour cost.
Cost of the action plan implementation: The estimated cost of implementing the action plan is determined by the stock holding cost, inspection and predictive diagnostic costs and labour costs.

The Risk Treatment.

The risk treatment is a summary of the best possible solutions to each risk in the risk register. The risk treatment can be determined once all the relevant information about a risk is available as contained in the risk register.

The risk treatment contains the following:

- A reference number for each risk: The reference number relates to the specific risk in the risk register.
- A possible treatment for each risk: Under this heading is a short description of the best possible treatment of the risk.
- The following sections are derived using the risk register:
  - The risk level before the implementation of the action plan.
  - The total cost before the implementation of the action plan determined by:
    \[ \text{Total cost} = \text{Downtime Cost} + \text{Repair Cost} \]  
  - The risk level after the implementation of the action plan.
  - The total cost after the implementation of the action plan determined by:
    \[
    \begin{align*}
    \text{Total Cost (after implementation of action plan)} &= \text{Downtime Cost} + \text{Repair Cost} + \text{Action Plan Cost}. \\
    \end{align*}
    \]
- Risk factor improvement: The risk factor improvement is a qualitative measure of the improvement of the risk by implementation of the action plan, and is represented by the following:

<table>
<thead>
<tr>
<th>LEGEND</th>
<th>DESCRIPTION</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Extreme Risk</td>
<td>100%</td>
</tr>
<tr>
<td>H</td>
<td>High Risk</td>
<td>75 %</td>
</tr>
<tr>
<td>M</td>
<td>Medium Risk</td>
<td>50 %</td>
</tr>
<tr>
<td>L</td>
<td>Low Risk</td>
<td>25 %</td>
</tr>
</tbody>
</table>

  Table 5. Value of risk levels.

In equation 6 each level of risk represents 25% as illustrated in table 5:

\[
\text{Risk Factor Improvement} = \text{Risk level (before action plan)} - \text{Risk level (after action plan)} \%
\]  

The risk treatment is essentially a summary of all the costs involved, and is used to make decisions based on the estimated cost benefit of each risk treatment.
**The Risk Action Plan.**

The function of the Risk Action Plan is to guide the maintenance personnel in the implementation of the risk treatment. It contains:

- A detailed summary of the risk.
- A proposed action to resolving the risk (Risk treatment).
- Parts and Labour requirements to implement the risk treatment. (Resource Requirements.)
- Allocation of responsibilities.
- Schedule for implementation and the frequency of the tasks if an inspection is involved.
- Reporting and monitoring required on the action plan.

To ensure the implementation of the risk analysis and to close the loop of continuous improvement the risk implementation register concludes the risk analysis.

**The Risk Implementation Register.**

The risk implementation plan forms part of the reporting function on a monthly basis and its function is to promote continuous improvement of the risk analysis.

The risk implementation register contains three sections:

- A replacement record for each machine to keep history on the replacement of parts at certain machine hours.
- An inspection record for each machine to keep history on the frequency of inspections.
- An implementation date for each machine.

The risk implementation register also forms part of the data gathering function. Thus the maintenance strategy is partially controlled by the risk analysis. These two items are combined in the life cycle management to ensure availability and reliability.

Maintenance cannot be managed without a proper and efficient control function. Control includes benchmarking, risk analysis and reliability management.

**CONCLUSION**

The maintenance strategy never becomes a fixed model, the maintenance strategy of any company changes to adapt to the changes in the company and the strategy of the company. Referring the reader to the previous section, were the maintenance plan construction was compared to building a house. If the foundations of the house change it implies that the maintenance requirements changed, it also implies that the resources needed to accomplish the maintenance requirements and the systems needed to manage them, changed, because these are the walls and roof of the construction.

Controlling the maintenance strategy through data analysis involves gathering the correct KPI’s. If maintenance data are not measure, it cannot be controlled. Controlling maintenance means controlling the input and measuring the output against
the input, this leads to controlling maintenance costs. Getting accurate and complete data form the maintenance personnel is often a very tedious and time consuming task, implementing and controlling the data gathering function by introducing a standard operating procedure for each task of data gathering is a practical way to ensure data is accurate, complete and available.

Maintenance costs in the mining industry is significantly high which can result from the high availabilities and reliability required by the mining industry. Although maintenance systems improve the profitability of a maintenance agreement, it should be realised that the core drivers behind maintenance systems are improved availability and reliability.